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Phytoremediation potential of some heavy metals by water hyacinth

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ABSTRACT

The phytoremediation potential of water hyacinth plant (*Eichhornia crassipes*) was investigated on some metals. The plants were grown for 7 days each in phytoremediation tanks containing a solution of 100 ppm concentration of either Potassium (K), Sodium (Na), Zinc (Zn), Lead (Pb), Iron (Fe), Cadmium (Cd), Magnesium (Mg), Copper (Cu) or Calcium (Ca). The change in fresh weight was examined. The percent removal of the metals by the plant was determined using atomic absorption spectrometry on the acid digest of the plant. The biomass decreased insignificantly (P>0.05) in the water hyacinth grown in the test solution and increased by 5.72 % (g/g) in the control. Metal uptake occurred to varying degrees. The highest amount of metal uptake per dry weight of water hyacinth was 13.52 ppm of potassium and lowest, 0.01ppm of lead.

Keywords: Metals, phytoremediation, water hyacinth.

INTRODUCTION

Waters in many areas of the world are polluted with toxic metals from industrial effluents, radionuclide, hydrocarbons from oil refineries and pesticides from agricultural industries. Unlike the organic wastes, metals are non-biodegradable, trace and heavy metals such as Arsenic, Selenium, Zinc, Manganese, Lead, Mercury and Cadmium need to be removed from the environment (Alluri et al., 2007).

Most of the remedial technologies in the treatment or removal of metallic wastes are quite expensive and injurious to health.
Phytoremediation, which is the use of plants and their associated microorganisms, is one of the recent technologies which guarantee an effective, economical and sustainable means to achieve this end for developing countries (Macek et al., 2000; Susarla et al., 2002; Xia et al., 2003. Ghosh and Singh, 2005).

Phytoremediation encompasses five processes of metal removal from soil or water. These processes include: rhizofilteration, phytostabilisation, phytoextraction, phytovolatilization and phytodegradation. Rhizofilteration is the use of plants to absorb, concentrate and precipitate organic and inorganic pollutants from aqueous sources (Dushenkov et al., 1995; Salt et al., 1995; Flathman and Lanza, 1998; Zhu et al., 1999). Phytostabilisation involves the use of plants (roots) to immobilize the inorganic contaminant through the process of sorption, precipitation, complexation or metal valence reduction in the soil or aqueous environment (Berti and Cunningham, 2000; Ghosh and Singh, 2005). Phytoextraction which is also known as phytoaccumulation is the removal or absorption, concentration and precipitation of the elemental pollutant into the plant material (Salt et al., 1995; Salt et al., 1997; Rulkens et al., 1998). Phytovolatilization involves the extraction, transformation of the pollutant into a volatile and less toxic form which is then transpired into the atmosphere (Ghosh and Singh, 2005). This process has been used to remediate mercury, selenium and tritium (Banuelos, 2000; Henry, 2000; Dushenkov, 2003). Phytodegradation is the uptake and breakdown of organic molecules to simpler forms by plants using plant enzymes such as the dehalogenases, oxygenases and reductases (Black, 1995; Chaudhry et al., 1998).

About 400 plant species have been identified as metal hyperaccumulators (Prasad and Freitas, 2003). Four aquatic plants; Cattail (*Typha domingensis*), duckweed (*Lemna obscura*), Hydrilla (*Hydrilla verticillata* Royle) and Swamp lilly (*Crinum americanum*) have been reported to hyperaccumulate Selenium (Se) (Carvalho and Martin, 2001). *E. crassipes*, *L. minor* and *A. pinnata* have been reported to phytoremediate Cadmium (Cd), Chromium (Cr), Cobalt (Co), Nickel (Ni) and Lead (Pb) (Upadhyay and Tripathi, 2007).

The success of phytoremediation greatly depends on the photosynthetic activity and the growth rate of plants. Water hyacinth, which is the world's most noxious aquatic plant, has a prolific growth rate and thus the potential to clean up most wastes (Xia and Ma, 2005).

The aim of the present study was to evaluate the phytoremediation potential of water hyacinth (*Eichhornia crassipes*) on some selected heavy metals.

MATERIALS AND METHODS

Plant collection

The water hyacinth (*Eichhornia crassipes*) plants used in the study were obtained from the Lagos lagoon behind the University of Lagos, Akoka Campus, Lagos State, Nigeria. This was authenticated by Dr. Adekunle Adedotun in the Department of Botany and Microbiology, University of Lagos, Akoka, Lagos State, Nigeria. A specimen was kept in the herbarium with the voucher number WH105. Unwanted debris was removed from the plants before being washed with deionised water. The weeds were cultured in Hoagland's E-medium (Table 1) for two weeks for them to equilibrate (Carvalho and Martin, 2001).

Phytoremediation study

This study was conducted to investigate the metal uptake capacity of water hyacinth using such metals as: Potassium (K), Sodium (Na), Zinc (Zn), Lead (Pb), Iron (Fe), Cadmium (Cd), Magnesium (Mg), Copper (Cu) and Calcium (Ca).

These metals were of analytical grade obtained from Sigma (Sigma Chemical Co., London) and used in the form of salts; Potassium chloride, Sodium chloride, Zinc sulphate, Lead acetate, Iron sulphate, Cadmium chloride, Magnesium chloride, Copper sulphate and Calcium chloride. A solution of 100 ppm concentration of each of the salt in half strength Hoagland's E-medium was prepared (Carvalho and Martin, 2001). And four liters of each of the salt solution was added into separate phytoremediation tanks. The weight of the water hyacinth plants were taken before they were introduced into the different solution. The plants were exposed to the different solution for a period of one week with a photo period of 12 hours light and 12 hours dark cycle. The plants were left in the laboratory under the conditions of average temperature ranging between 24 °C and 31 °C, relative humidity between 68 in the night and 86 in the day and the average period of sunlight was 7 h per day. A control experiment was set up with no metal added to half-strength Hoagland's E-medium. Three replicate experiments (phytoremediation tanks) were set up for each test and the control. After 7 days of metal exposure, the plants were digested for metal extraction and analysis.

Metal extraction from plant

The plants were removed from the phytoremediation tank after one week and digested according to the method of Carvalho and Martin (2001). Each plant was weighed, cut, and blended. The plant was allowed to dry in an oven (SD 93114624, Gallenkamp, United Kingdom) at 45 °C for 48 hours. A dry weight was taken and each sample was placed in a 250 ml round bottom flask and 5 ml of 16 M nitric acid and 5 ml of deionized water were added. Each sample was heated for 10 to 15 minutes at 90 °C on a heating mantle. The sample was then allowed to cool and another 5 ml of 16 M HNO_3 was added and heated for the second time at 90 °C for 30 minutes. This step was repeated and 2 ml of deionized water and 3 ml of 30% hydrogen peroxide solution were gently added, and the mixture was heated until effervescence stopped. A 5 ml of 12 M HCl was added and this was refluxed for 10 to 15 minutes. The sample was allowed to cool and then diluted to 100 ml with 6% (v/v) HCl. The sample digest was vacuum filtered using a 0.45 µm Millipore membrane filter. The filtrate obtained was diluted to 100 ml and used immediately for metal analysis.

Metal analysis

Standard solutions of the metals to be analyzed were prepared. The atomic absorption spectrophotometer (AAnalyst 200, Perkin Elmer Inc., United State) was set with power on for 10 minutes to stabilize. The standard metal solutions were injected to calibrate the AAS using acetylene as the carrier gas. An aliquot of both the metal solution taken from the phytoremediation tank and that obtained from the plant digest were injected and the concentrations were obtained from the AAS.

Data analysis

The weight of water hyacinth and metal concentration were given to 2 decimal places and were reported as means ± SEM of triplicate results. Significant differences between metal uptake and control were assessed by a one-way analysis of variance (ANOVA) and the Student's t-test with two-tail probabilities of less than 0.05 considered significant using the Microsoft Office Excel (2003).

RESULTS

Effect of metals on weight of water hyacinth

The results obtained in this phytoremediation experiment showed that the metals used in this study reduced the fresh biomass weight with varying degree (Table 2). The percent fresh biomass weight loss was highest; 7.8% with sodium metal, 5.43% with zinc and least 3.11% with iron. And the fresh biomass weight in the control experiment increased by 5.72%. However, the change in weight of the test and control plants over the phytoremediation period was not significant (P>0.05).

Metal uptake capacity by water hyacinth

The various metals assayed in the experiment were found present in the acid digest of both the control and test plants. However, the concentration of the metals (Potassium, Lead, Cadmium and Copper) in the test plants differed significantly when compared to the control (Table 3). Due to the disparity in weight of the plants used in each experiment, the metal uptake capacity was expressed as concentration of metal uptake per dry weight of the plants (Table 4).

DISCUSSION

The results (Table 3) showed that the water hyacinth can phytoremediate metals such as Potassium, Sodium, Zinc, Lead, Iron, Cadmium, Magnesium, Copper and Calcium. Water hyacinth has been reported to bioaccumulate some of these metals (Carbonell et al., 1998; Zhu et al., 1999; Ingole and Bhole, 2003; Mahmood et al., 2005; El-Gendy et al., 2006; Tiwari et al., 2007; Upadhyay and Tripathi, 2007). However, the reduction in the concentration of potassium, lead, iron and magnesium in the acid digest of the test plants could be as a result of the fact that the average weight of the

Table 1: Hoagland's E-Medium formulation used for water hyacinth culture.

Composition	**Stock solution**	**[1]Final medium Used (mL/L of deionised water)**
1. $MgSO_4 \cdot 7H_2O$	24.6 g/100mL	1.0
2. $Ca(NO_3)_2 \cdot 4H_2O$	23.6 g/100mL	2.3
3. KH_2PO_4	13.6 g/100mL	0.5
4. KNO_3	10.1 g/100mL	2.5
5. Micronutrients	Micronutrient Solution g/L (H_3BO_3,2.86; $MnCl_2 \cdot 4H_2O$, 1.82; $ZnSO_4 \cdot 7H_2O$, 0.22; $Na_2MoO_4 \cdot 2H_2O$, 0.09; $CuSO_4 \cdot 5H_2O$, 0.09)	0.5
6. Fe·EDTA	Fe·EDTA Solution g/250 mL ($FeCl_3 \cdot 6H_20$,0.121; EDTA, 0.375)	20.0

[1]The pH of final medium was adjusted to 5.8 with NaOH or HCI, autoclaved and diluted to half-strength before use for water hyacinth culture.

Table 2: Biomass (g) of water hyacinth 7 days after exposure to metals.

Metals	**[1]Initial weight (A)**	**[1]Final weight (B)**	**B-A**	**% Weight loss/gain**
Potassium	218.00 ± 20.05a	201.00 ± 13.33a	-17.00	7.80
Sodium	285.40 ± 40.55a	275.20 ± 17.06a	-10.20	3.57
Zinc	307.80 ± 27.89a	291.10 ± 10.47a	-16.70	5.43
Lead	285.40 ± 51.57a	272.00 ± 28.65a	-13.40	4.70
Iron	222.00 ± 16.82a	215.10 ± 14.78a	-6.90	3.11
Cadmium	198.50 ± 8.46a	188.20 ± 10.75a	-10.30	5.19
Magnesium	235.10 ± 15.94a	225.40 ± 11.99a	-9.70	4.13
Copper	233.00 ± 26.72a	224.00 ± 18.56a	-9.00	3.86
Calcium	245.10 ± 34.12a	235.00 ± 22.65a	-10.10	4.12
Control	309.50 ± 21.55a	327.20 ± 25.36a	17.7	5.72

[1]Data represents mean ± SEM of triplicate results. Mean weight of water hyacinth plant before and after the experiment for each metal followed by different alphabets differ significantly ($p<0.05$).

Table 3: Metal concentration (ppm) in water hyacinth grown in solutions without (control) and with metals.

Metals	**Conc. in control**	**Conc. in test solution**
Potassium	212.69 ± 9.78a	142.24 ± 5.26b
Sodium	3.61 ± 0.56a	3.89 ± 1.12a
Zinc	3.79 ± 1.08a	4.35 ± 0.94a
Lead	2.19 ± 0.64a	0.45 ± 0.18b
Iron	20.04 ± 2.83a	17.78 ± 3.01a
Cadmium	2.50 ± 0.89a	19.95 ± 3.34b
Magnesium	8.12 ± 2.06a	7.35 ± 1.99a
Copper	0.77 ± 0.23a	7.38 ± 0.56b
Calcium	29.11 ± 4.51a	29.84 ± 3.89a

[1]Data represents mean ± SEM of triplicate results. Mean metal concentration in plants between test and control experiment followed by different alphabets differ significantly ($p<0.05$). Conc. = Concentration.

Table 4: Metal uptake capacity (ppm) per dry weight of water hyacinth.

Sample	[1]Dry weight of test plant (g)	Metal (Analyte)	[1]Conc. of metal in test plant (B)	[1]Conc. of metal in control plant (A)	Conc. of metal uptake in plant (B-A)
1	5.60 ± 1.32	Potassium	25.40 ± 1.27a	11.88 ± 0.97b	13.52
2	7.60 ± 1.05	Sodium	0.51 ± 0.11a	0.20 ± 0.06b	0.31
3	13.00 ± 2.16	Zinc	0.34 ± 0.09a	0.21 ± 0.04b	0.13
4	3.50 ± 1.20	Lead	0.13 ± 0.06a	0.12 ± 0.07a	0.01
5	15.50 ± 2.56	Iron	1.15 ± 0.01a	1.12 ± 0.15a	0.03
6	22.20 ± 3.89	Cadmium	0.90 ± 0.13a	0.14 ± 0.04b	0.76
7	4.00 ± 1.68	Magnesium	1.84 ± 0.24a	0.45 ± 0.10b	1.39
8	15.20 ± 2.45	Copper	0.49 ± 0.07a	0.04 ± 0.01b	0.45
9	17.50 ± 3.02	Calcium	1.71 ± 0.21a	1.63 ± 0.32a	0.08

[1]Data represents mean ± SEM of triplicate results. Dry weight of control plant (g) = 17.90 ± 1.98. Means between test and control experiment for each analyte followed by different alphabets differ significantly ($p<0.05$).

control plants is higher than the test plants. But when the metal uptake capacity was expressed as concentration of metal uptake per dry weight of the plants (Table 4), the highest metal uptake capacity was observed with potassium (13.5 ppm) and the least with lead (0.01 ppm). More so, all the metals assayed were found to be removed by water hyacinth but at different degrees (Table 4). The amount of metal removed (Table 4) with respect to lead (Pb), Copper (Cu) and Zinc (Zn) were lower than those reported in literature (El-Gendy et al., 2006). However, this may be due to the effect of the concentration of the metal in the plant growth medium. Studies have shown that the phytoremediation efficiency of metals greatly depends on the concentration of such metals in solution, and the higher the concentration of the metals in the solution the lower the removal efficiency (Carvalho and Martin, 2001; Ingole and Bhole, 2003; Keith et al., 2006).

Conclusion

The study showed that water hyacinth (*Eichhornia crassipes*) could effectively phytoremediate contaminated water containing metals such as Potassium (K), Sodium (Na), Zinc (Zn), Lead (Pb), Iron (Fe), Cadmium (Cd), Magnesium (Mg), Copper (Cu) and Calcium (Ca), thus; reducing the environmental hazard that could arise from untreated waste water to the ecosystem.

Future study will examine the potential of water hyacinth as a bio-agent to phytoremediate polycyclic aromatic hydrocarbon which is a major toxicant resulting from oil spill in the oil producing states in Nigeria.

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